PREPRINT

EXPEDIENT SPALL REPAIR METHODS AND EQUIPMENT FOR AIRFIELD PAVEMENTS

Michael I. Hammons
Air Force Research Laboratory

Athar Saeed
Applied Research Associates
P.O. Box 40128
Tyndall Air Force Base, FL 32403

AUGUST 2009

Distribution Statement A:
Approved for public release; distribution unlimited.

REPORT DOCUMENTATION PAGE

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
01-AUG-2009	Conference Paper	01-OCT-2007 -- 30-JUL-2009

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Expedient Spall Repair Methods and Equipment for Airfield Pavements	FA4819-07-D-0001

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62102F

6. AUTHOR(S)	5d. PROJECT NUMBER
*Hammons, Michael I.; +Saeed, Athar	4915

5e. TASK NUMBER
D1

5f. WORK UNIT NUMBER
4915D14E

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
+Applied Research Associates P.O. Box 40128 Tyndall Air Force Base, FL 32403	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
*Air Force Research Laboratory Materials and Manufacturing Directorate Airbase Technologies Division 139 Barnes Drive, Suite 2 Tyndall Air Force Base, FL 32403-5323	AFRL/RXQD
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-RX-TY-TP-2009-4552

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement A: Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
Ref AFRL/RXQ Public Affairs Case # 09-117. Submitted for presentation at the 2010 Annual Transportation Research Board (TRB), 10-14 Jan 2010, in Washington DC. Document contains color images.

14. ABSTRACT

Selected equipment and procedures were evaluated to expeditiously prepare a spall for repair with rapid-setting materials. The objective of this research was to develop one or more methods to excavate and prepare a 2-foot-wide by 2-foot-long by 4-inch-deep spall for placement of a rapid-setting repair material in 15 minutes or less. A secondary objective was to correlate various excavation methods with a relative life expectancy of the repair. For five excavation methods, 2-foot-wide by 2-foot-long by 4-inch-deep spalls were excavated in triplicate. The spalls were subsequently repaired using a typical rapid-setting spall repair material. The efficacy of the repair methods and equipment were evaluated based upon petrographic examination of the substrate excavation, production rate, total production rate, in-situ tensile pull-off strength, direct shear bond strength, and performance under simulated F-15 wheel loading. Each of the methods evaluated had a significant improvement in production rate over the 30-pound jackhammer, the standard Department of Defense spall repair excavation method. The most efficient method was a cold planer, which, on average, was approximately 58 percent more efficient than the jackhammer. Of the methods evaluated, only the cold planer can meet the requirement of being able to excavate 2-foot square by 4-inch deep spall in no more than 15 minutes.

15. SUBJECT TERMS

rigid pavement, spall, spall repair, equipment, procedures

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			R. Craig Mellerski
U	U	U	UU	20	**19b. TELEPHONE NUMBER** (Include area code)

1   **EXPEDIENT SPALL REPAIR METHODS AND EQUIPMENT**
2   **FOR AIRFIELD PAVEMENTS**
3
4
5

6   Michael I. Hammons, PhD, PE (corresponding author)
7   Research Engineer
8   Air Force Research Laboratory
9   104 Research Road, #9742
10   Tyndall AFB, FL 32403
11   (850) 283-3605 (phone)
12   (850) 283-4932 (fax)
13   Michael.Hammons@tyndall.af.mil
14
15
16   Athar Saeed, PhD, PE
17   Principal Engineer, Applied Research Associates, Inc.
18   Contract Research Engineer, Air Force Research Laboratory
19   104 Research Road, #9742
20   Tyndall AFB, FL 32403
21   (850) 283-3718 (phone)
22   (850) 283-4932 (fax)
23   Athar.Saeed@ARA.com
24
25
26
27   Submitted
28   August 1, 2009
29
30
31
32

Words		4752
Figures	(8 @ 250)	2000
Tables	(1 @ 250)	250
Total		7002

34
35

1   **ABSTRACT**

2   Selected equipment and procedures were evaluated to expedite repair of spalls with rapid-
3   setting materials. The objective was to develop one or more methods to excavate and prepare
4   a 2-foot-wide by 2-foot-long by 4-inch-deep spall for placement of a rapid-setting repair
5   material in 15 minutes or less. A secondary objective was to correlate various excavation
6   methods with a relative life expectancy of the repair. For five excavation methods, 2-foot-
7   wide by 2-foot-long by 4-inch-deep spalls were excavated in triplicate. The spalls were
8   subsequently repaired using a commonly-used rapid-setting cementitious repair material. The
9   efficacy of the repair methods and equipment were evaluated based upon petrographic
10   examination of the substrate excavation, production rate, total production rate, in-situ tensile
11   pull-off strength, direct shear bond strength, and performance under simulated F-15 wheel
12   loading. Each of the methods evaluated had a significant improvement in production rate
13   over the 30-pound jackhammer, the standard Department of Defense spall repair excavation
14   method. The most efficient method was a cold planer, which, on average, was approximately
15   58 percent more efficient than the jackhammer. Of the methods evaluated, only the cold
16   planer can meet the requirement of being able to excavate 2-foot square by 4-inch deep spall
17   in no more than 15 minutes.
18
19
20
21   Abstract: 201 words
22

1   **BACKGROUND**

2   A spall is described as cracking, breaking, chipping, or fraying of a concrete slab near a joint
3   or crack. Spalls may be caused one of more of the following mechanisms:
4   • Durability issues such D-cracking and alkali-silica reaction (ASR);
5   • Inadequate maintenance, e.g., allowing foreign matter to collect in the joints;
6   • Improper construction procedures and details such as misaligned dowel bars,
7   sawing joints too late, not sawing joints to adequate depth, or excessive working of the fresh
8   concrete leading to a paste-rich mix;
9   • Fatigue caused by repeated mechanical loading of the joint by high-pressure aircraft
10   tires; or
11   • Damage from munitions.
12   Spalls may be partial depth or full depth. In the case of both full- and partial-depth
13   spalls, foreign object debris (FOD) may be generated, and rough surfaces at the spall may
14   damage aircraft tires. Full-depth spalls reduce the structural capacity of the slab and
15   exacerbate fatigue failure under repeated loading (1).
16   The normal procedure for repairing a spall is outlined in Engineering Technical Letter
17   (ETL) 07-8 as follows (2):

18   • Remove loose debris from the damaged area.
19   • Mark the outer edge of the repair (2 to 3 inches beyond the damaged area).
20   • Saw the edges of the repair to a depth of at least 2 inches (50 millimeters). Do not
21   feather the repair.
22   • Make additional cuts within the bounds of the repair edges using a concrete saw.
23   • Make transverse cuts on each end 1.5 inches (38 millimeters) from the ends of the
24   repair.
25   • Remove the remaining material using a small jackhammer (30 pounds or less).
26   • Remove loose debris from the repair area.
27   • Wash the repair area with a high-pressure washer or use water and a scrub brush.
28   • Remove any loose material or lodged debris from the joint or crack.
29   • Place a small bead of caulk over the joint or crack.
30   • If using a cement-based repair material, soak the repair and leave saturated surface
31   dry (SSD).
32   • Place a compressible insert material over any joint or crack in the repair area.
33   • Mix the materials in accordance with manufacturers' recommendations.
34   • A temperature gun (thermometer) should be used to check the temperature of the
35   water and material before mixing, as well as the temperature of the material during mixing.
36   • Pour/place the material in the repair.
37   • Clean mixing and placement equipment immediately after use.
38   • When using cement repair materials, either wet cure or apply curing compound.
39   • Remove the compressible spacer insert after the repair has cured.
40   • Reseal the joint.

1   Because airfield operations are negatively impacted during the process of performing
2 spall repairs, the time required to perform spall repairs is critical to maintaining the flying
3 mission of the U.S. Air Force. The impact of the spall repair process on aircraft operations
4 can vary by degree, ranging from an inconvenience to the complete suspension of flight
5 operations.
6   The service life of a spall repair is dependent on many factors such as construction
7 quality, repair material properties, and loading conditions. The most important factor is often
8 the time required to construct a durable repair. As with any quick fix, there is often a tradeoff
9 between expediency and quality. Expedient spall repairs are made when time, equipment,
10 materials, and/or manpower are not available to perform a permanent repair. These extend the
11 serviceability of a pavement using utilitarian methods, but durability and long-term
12 performance may suffer as compared to permanent repair methods. Spall repairs at
13 expeditionary locations have failed sooner than expected based upon accelerated pavement
14 loading studies. Many of these repairs involve relatively non-uniformly shaped repairs that
15 are loaded within a few hours after placement (3).

16 **RESEACH OBJECTIVES AND SCOPE**

17 The objective of this research was to develop one or more methods that will allow field
18 personnel to excavate and prepare a 2-foot-wide by 2-foot-long by 4-inch-deep spall for
19 placement of a rapid-setting repair material in 15 minutes or less. A secondary objective was
20 to correlate various excavation methods with a relative life expectancy of the repair.
21   Selected equipment and procedures were evaluated to expeditiously prepare the spall
22 for repair with rapid-setting materials. For five excavation methods, 2-foot-wide by 2-foot-
23 long by 4-inch-deep spall were excavated in triplicate. The spalls were subsequently repaired
24 using a typical rapid-setting spall repair material. The efficacy of the repair methods and
25 equipment were evaluated based upon petrographic examination of the substrate excavation
26 production rate, total production rate, in-situ tensile pull-off strength, direct shear bond
27 strength, and performance under simulated F-15 wheel loading. An optimal method was
28 identified, and recommendations procedures were proposed.

29 **EXPERIMENT DESCRIPTION**

30 A series of experiments were performed using five excavation methods (treatments) on
31 nominal 2-foot-wide 2-foot-long by 4-inch-deep spalls:
32   • Saw cut and 30-pound jackhammer (baseline or current standard),
33   • Saw cut and a hydraulic breaker on a skid steer tractor,
34   • Multiple-blade gang saw with saw spacing at ¾ inch,
35   • Multiple-blade gang saw with saw spacing at 1½ inches, and
36   • Cold planer attachment for a skid steer loader.
37   After excavation, core samples were extracted from each treatment, and petrographic
38 examinations were performed. Final preparation for each method consisted of pressure
39 washing and excess water removal leaving the excavation clean and surface damp. The spalls
40 were repaired with a self-leveling cementitious repair material. A series of 2-inch-diameter

1 cores were cut through the repair material and into the substrate. The cores were used to
2 perform in-situ tensile pull-off tests to evaluate the bond between the repair material and the
3 substrate. Also, a series of 4-inch diameters cores were cut, and direct shear tests were
4 performed on the repair material/substrate interface. Finally, all spalls were trafficked for
5 1,500 passes using an F-15E load cart. The details of these experiments are presented in this
6 chapter.

7 **Substrate Description**

8 All excavations were conducted on a jointed, unreinforced Portland cement concrete
9 pavement at Tyndall AFB, FL. The pavement was approximately 20 years old at the time of
10 the experiment. The pavement consisted of 10-ft square slabs approximately 12 inches thick.
11 The slabs were supported by a dense-graded limestone subbase which overlies a poorly
12 graded (beach) sand subgrade. The aggregate in the concrete was crushed siliceous river
13 gravel, and the compressive strength of the concrete averaged 8260 psi.

14 **Excavation Equipment and Methods**

15 Each excavation method was conducted in triplicate. All spalls were required to have one
16 (and only one) side along a joint.

17 *30-lb Jackhammer*

18 The common method to remove material from a spall repair is to use a portable pneumatic
19 jackhammer. ACI RAP Bulletin 7 recommends that jackhammers larger than 30 lbs not be
20 used, because they may cause damage to the surrounding concrete (4). For this experiment a
21 2 ft by 2 ft area was cut using a walk-behind saw to a depth of approximately 4 inches. The
22 concrete inside the cut was removed with a 30-lb pneumatic jackhammer. A nail-point
23 breaker tip was used to break up the concrete, and a spade tip was used to dress the repair
24 area. Final clean up was performed by manually removing the rubble with a shovel, sweeping
25 around the hole, and vacuuming the fines from the hole.
26
27 *Hydraulic Breaker on Skid Steer Loader*

28 The spall was prepared using a hydraulic percussion breaker fitted to a wheeled skid steer
29 loader as shown in FIGURE 1. The breaker was powered by the auxiliary hydraulic system
30 on the loader. The breaker had an operating weight of 736 lbs and produced 1310 blows per
31 minute at a hydraulic flow rate of 17.2 gallons per minute yielding approximately 300 ft-lbs
32 of impact energy. The diameter of the nail-type breaker probe was 2.56 inches. Final clean up
33 was performed with a shovel, broom, and shop vacuum.

1

FIGURE 1 Hydraulic Breaker.

2   *Cold Planer*

3   Another set of holes was excavated using a Caterpillar Model PC206 Cold Planer powered
4   by a CAT 257B high flow skid steer loader as shown in FIGURE 2. The hydraulic system on
5   the loader was operated at the high setting (26 gallons per minute at 3,335 psi). The cold
6   planer, designed for restoration of asphalt and concrete surfaces for small paving jobs, has a
7   drum width of 24 inches. The drum featured 60 carbide-tipped conical bits. The skid steer
8   loader moves backwards while lowering the drum in to the concrete. During the course of the
9   excavation the cold planer depth adjustment to was set to 4½ inches, because it appeared that
10   the milling debris was precluding the planer from achieving its desired depth of 4 inches.
11   Final clean up was performed with a shovel, broom, and shop vacuum.
12

1

FIGURE 2 Cold Planer.

2   *Gang Saw*

3   The final sets of excavations were performed using a prototype multiple-blade (gang) saw
4   developed by Diamond Products. The total width of the saw blades was 24 inches. The saw
5   consisted of a blade shaft with multiple 18-inch-diamater diamond-tipped saw blades as
6   shown in FIGURE 3. The blade shaft was hydraulically driven by a Diamond Products
7   CC8000 rider saw powered by a 78-hp diesel engine. The distance between the saw blades
8   was variable, and two center-to-center spacings were employed (¾ inch and 1½ inches) for
9   this research.
10   The saw was employed twice at right angles to produce an orthogonal grid of saw
11   cuts. Three holes each were prepared with the saw blades spaced at ¾ inch or 1½ inches.
12   After the cuts were made, the material was removed with a 30-lb pneumatic jackhammer, and
13   final clean up was performed with a shovel, broom, and shop vacuum.

14

FIGURE 3 Gang Saw.

Measures of Merit

Production Rate

The data recorded for each spall excavation were time to complete the excavation, time to complete clean out, and the volume of material removed. The volume of material removed was estimated by carefully measuring the volume of water required to fill the excavation.
Two measures of production rate were employed: 1) excavation production rate and 2) total production rate. The *excavation production rate* is defined as the time required to excavate the spall using the equipment and method evaluated. The *total production rate* is defined as the time required excavating 1 cu ft of spall, removing rubble, and preparing the spall repair for placement of rapid-setting repair material.

Petrographic Examination

One 6-inch-diameter core sample was removed from the interior of one excavation from each treatment (leaving two excavations from each treatment intact). Additionally, one 6-inch-diameter core was extracted from the undamaged concrete around the excavation areas as a control. These samples were sent to the U. S. Army Engineer Research and Development Center (ERDC) at Vicksburg, Mississippi, where a petrographic exam was conducted to quantify any damage done to the substrate by the excavation method/equipment.

1   Ultrasonic reflection imaging (URI) was conducted on samples cored from the
2   substrate materials after the excavation of the spalls was completed. The objective of the URI
3   was to qualitatively identify levels of damage caused by various excavation techniques and to
4   relate that to performance observed from the various mechanical testing results.
5   URI is a new technique for imaging concrete that focuses on the mechanical
6   characteristics of the concrete paste and aggregate. It is particularly sensitive to locating
7   damaged or weak aggregates, entrapped and/or entrained air, or failure between various
8   interfaces. URI relies on a laboratory immersion scanning system to collect data from either
9   smooth cored or cut concrete surfaces.

10   *In-Situ Bond Strength*

11   The in-situ tensile pull off test is described by the International Concrete Repair Guideline
12   No. 03739 (5). This protocol, which is based upon ASTM D4541 (6), allows the user to
13   evaluate the in-situ tensile bond strength. A core bit was used to drill through the repair
14   material and into the substrate. A rigid disc was attached to the top of the drilled core using a
15   high-strength adhesive. A testing device applied a tensile force to the rigid disc at a constant
16   rate until fracture occurred. The tensile force and location of the fracture (at the adhesive, at
17   the bond interface, within the repair material, or within the substrate) were recorded.

18   *Direct Shear Strength*

19   An AFRL-developed testing protocol was employed to measure the direct shear strength of
20   the bond interface on 4-inch diameter cores extracted from the spall repairs. A direct shear
21   test apparatus was fabricated in the shops at AFRL. The apparatus consisted of two clamping
22   yokes designed to secure the core to a base plate. A third yoke (or loading yoke) was
23   positioned near the end of the core to transmit the shearing force to the core. Leather shims
24   were employed to insure uniform contact between the core and the yokes at all contact areas.
25   The apparatus and core were placed in a Forney Model LT-920-D2 universal testing machine
26   capable of a maximum compressive force of 400,000 lbs, and the test was conducted at a
27   loading rate of approximately 500 lbs/min. The load at fracture was recorded, and the
28   shearing force at failure was calculated at the load at fracture divided by the cross-sectional
29   area of the core.

30   *Performance under Simulated Aircraft Trafficking*

31   The spall repairs were evaluated under 1,500 passes of AFRL's F-15E load cart. A single-lane
32   trafficking pattern was used in which all tire loads were applied to the center of the spall
33   repair area. One traverse of the spall field was defined as two passes (one pass up and one
34   pass back). The wheel loading was 35,200 lbs. At 25, 50, 75,100, and every 100 passes
35   thereafter trafficking was paused, and the spall repairs were inspected and photographed. No
36   active sensors or instrumentation were employed.

37   *Spall Repair Material*

38   A rapid-set spall repair material that has been tested at AFRL/RXQ for a related research
39   project was selected for this study. It is a blend of propriety cements, ASTM concrete grade

1 sand, air entrainment agent, and a high-range water reducer. The manufacturer recommends
2 its use for neat applications from ½ to 4 inches thick. The results of material properties tests
3 conducted by AFRL on the spall repair material are shown in TABLE 1.
4

TABLE 1 Strength Results for Repair Material

Age, hrs	Compressive Strength by ASTM C39, psi	Flexural Strength by ASTM C78, psi	Slant Shear Bond Strength by ASTM C 882, psi
2	N/A	705	1120
3	4480	635	1170
24	6070	550	1220

5

6 **EXPERIMENTAL RESULTS**

7 **Production Rate**

8   The times required to perform critical operations in spall repair preparations were observed
9   and recorded for each trial and excavation method. As previously described, two measures of
10 production rate were employed: 1) excavation production rate and 2) total production rate.
11 The volume of each excavation was also documented by recording the volume of water
12 required to rapidly fill each excavation. The production rate was then calculated by forming
13 the ratio of the time required to the volume of the excavation in cubic feet, yielding a
14 production rate in units of minutes/cubic feet. The timing of operations started when the
15 equipment first touched the pavement. The total production time included the time required
16 to remove all debris and blow the area clean of any residual fine materials using compressed
17 air.
18   FIGURE 4 presents the results of the excavation rate measurements. The mean value
19 of excavation rate is represented by the small squares, and the whisker bars represent ±95
20 percent confidence intervals on the mean. There was considerable scatter in the data, as
21 indicated by the magnitude of the confidence intervals. Comparing only mean values of
22 excavation rate revealed that the 30-lb jackhammer, the typical method of excavating spall
23 repairs, was the least efficient method. The most efficient method was the cold planer, which,
24 on average, was approximately 58 percent more efficient than the jackhammer. The second
25 most efficient method was the hydraulic breaker, followed by gang saw with spacing at 1½
26 inches and ¾ inch.
27   A pair wise t-test procedure was used to compare the means to determine if the
28 observed differences in the mean value were statistically significant given the large scatter of
29 the data. Using these analyses, we observed that the production rates for the 30-lb
30 jackhammer are statistically different from those of the cold planer, hydraulic breaker, and
31 the gang saw at 1½-inch spacing. We conclude that each of these methods is a significant
32 improvement in production rate over the 30-lb jackhammer.

1   A similar analysis was performed for total production rate. The results were similar to
2 that for excavation rate, except that the difference between the mean values for jackhammer
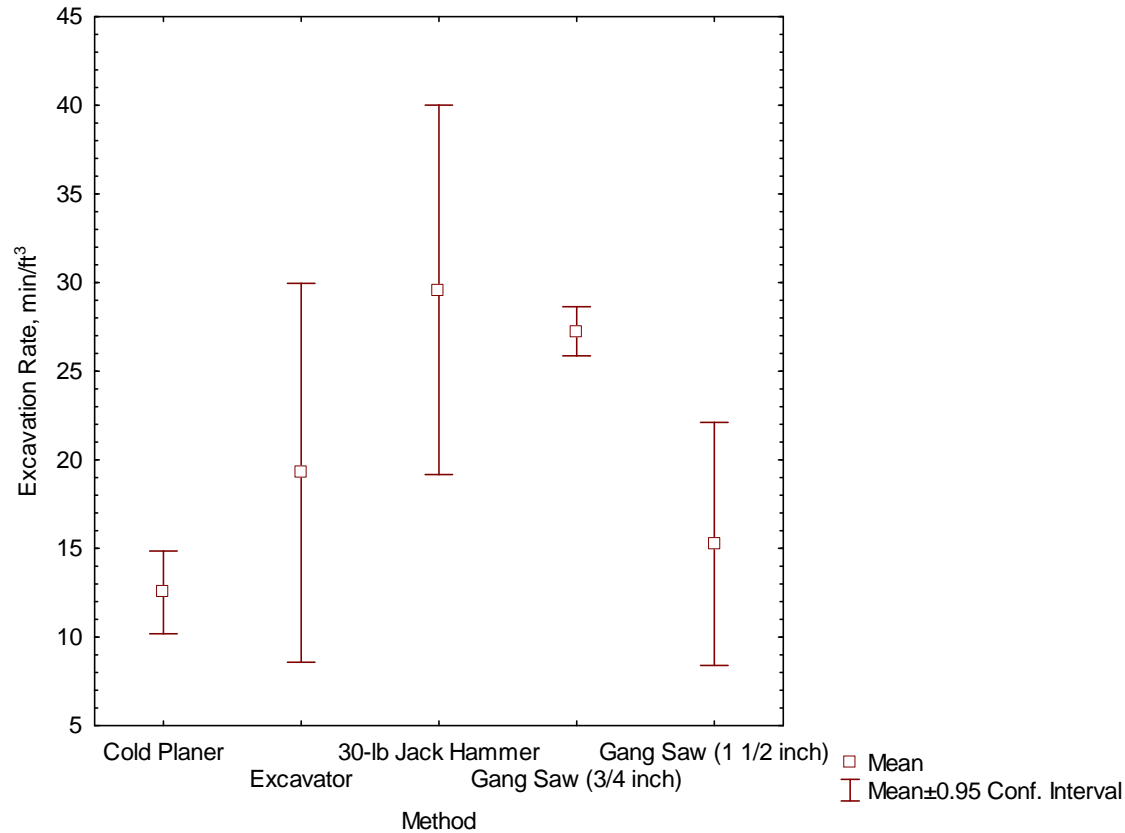3 method and the hydraulic breaker were significant in this case.

4

FIGURE 4 Excavation Test Results.

5 **Pre-Trafficking In-Situ Pull-Off Experiments**

6 At the outset of the experiments, as many of the 2-inch-diameter cores were drilled as
7 possible within the area allowed. A number of the cores were broken or debonded during the
8 coring process; therefore, number of replicates varied from spall-to-spall.
9   The results of the pre-trafficking in-situ pull-off experiments are summarized in the
10 plot shown in FIGURE 5. The greatest observed mean pull-off strength was for the cold
11 planer, followed, in order, by the jackhammer, gang saw at 1½ inches spacing, gang saw at ¾
12 inch spacing, and finally the hydraulic breaker. However, the scatter in the data is quite large,
13 and statistical analysis was required to evaluate the significance in the observed means. Pair
14 wise t-tests were conducted on each of the observed treatments, and the they indicated that
15 only the differences in the means between the hydraulic breaker and cold planer and
16 hydraulic breaker and jackhammer were statistically significant at the 95 percent confidence
17 level; thus we could not statistically distinguish between the means of the other treatments at
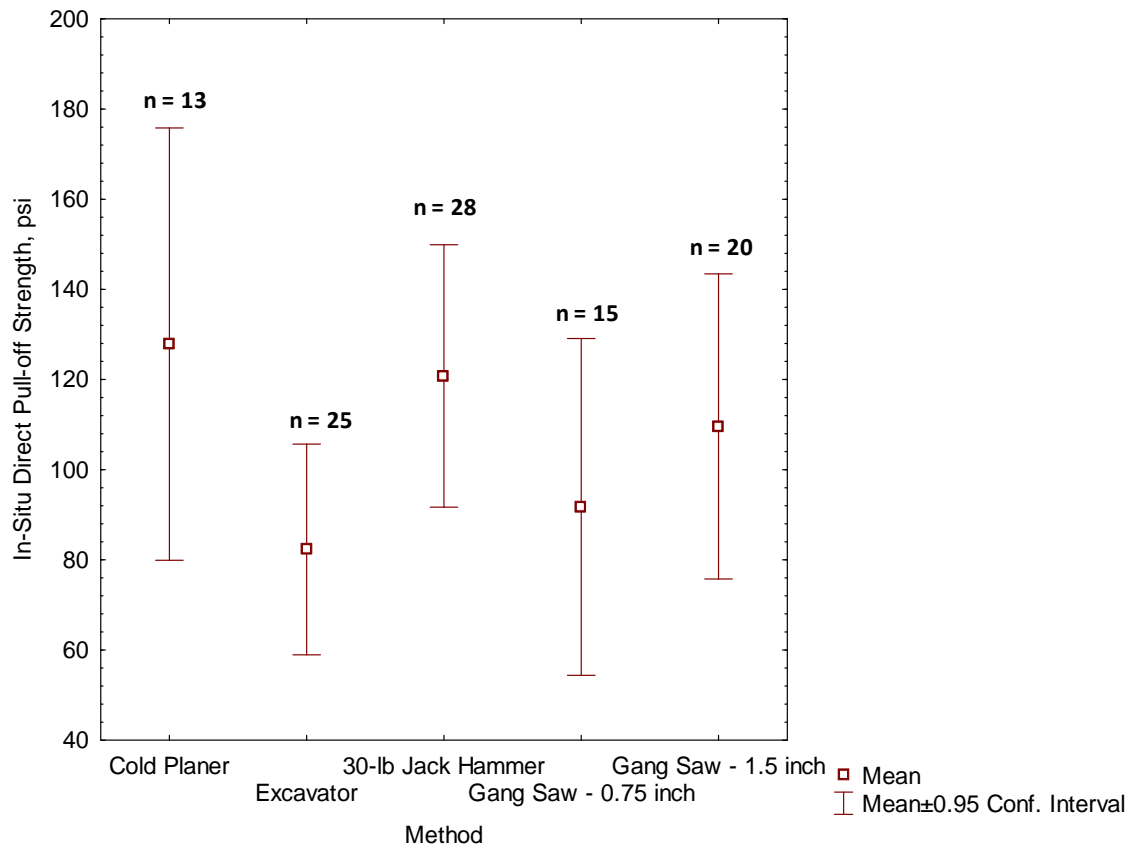18 the 95 percent confidence level.

FIGURE 5 Pre-trafficking In-situ Direct Pull-off Results.

2   **Pre-Trafficking Direct Shear Experiments**

3   The experiment plan was to obtain 4 replicates from each spall; however, some cores broke
4   or became debonded during the coring operation. Most spalls produced three or four cores
5   which could be evaluated in direct shear experiments.
6   The results of the pre-trafficking in-situ pull-off experiments are summarized in the
7   plot shown in FIGURE 6. The greatest observed mean direct shear strength was for the cold
8   planer, followed, in order, by the jackhammer, gang saw at 1½ inches spacing, gang saw at ¾
9   inch spacing, and finally the hydraulic breaker. However, once again, the scatter in the data is
10   quite large, and statistical analysis was required to evaluate the significance in the observed
11   means. For these experiments, the t-tests indicated that only the differences in the means
12   between the hydraulic breaker and jackhammer and gang saw were statistically significant at
13   the 95 percent confidence level.
14   A regression analysis was performed to determine the strength of the correlation
15   between these two indications of bond strength. This analysis indicated that the two metrics
16   of bond strength are positively correlated with a correlation coefficient (R^2) of 0.66. These
17   results indicated that both the in-situ tension pull-off test and direct shear test are indicators
18   of the bond strength, with additional testing and numerical analysis required to improve the
19   correlation between the two test methods.

1   Because the direct shear strength test is not an accepted test method per ASTM, the
2   results of the direct shear strength tests were not be used to draw conclusions concerning the
3   efficacy of the methods until further development and analysis of this testing methodology is
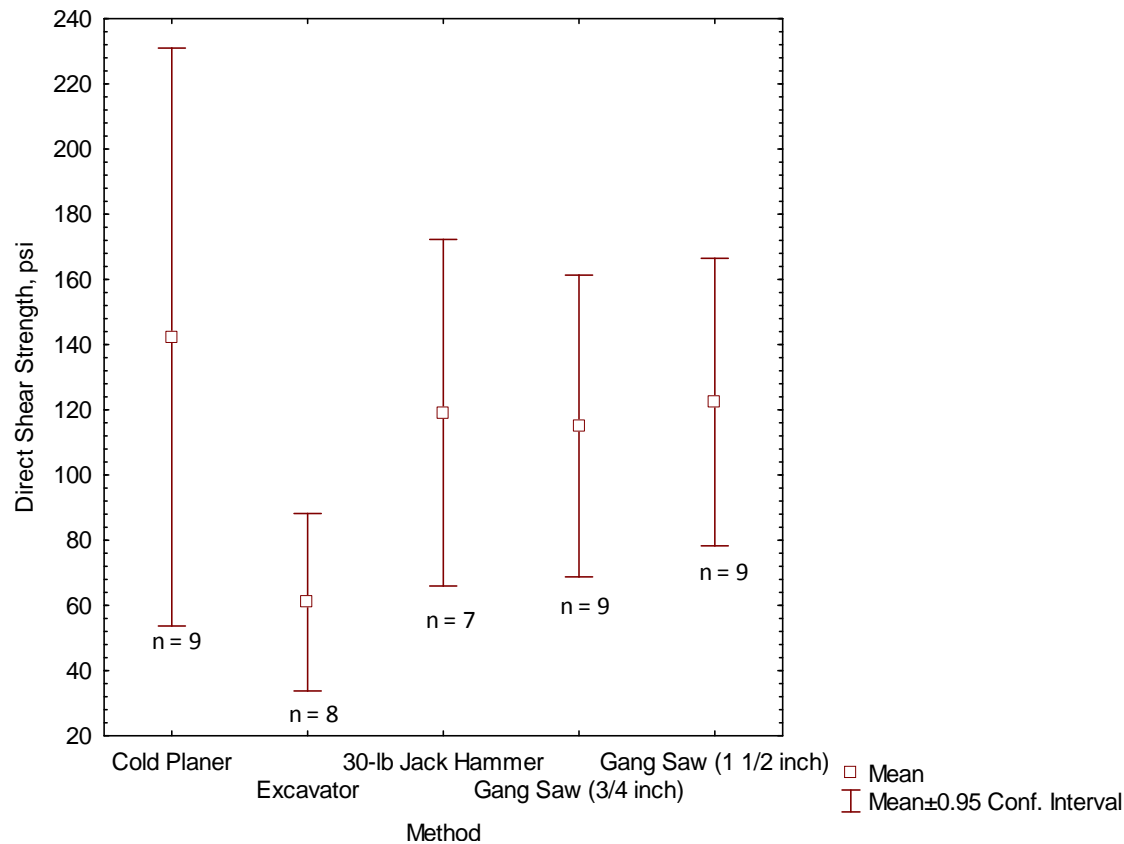4   conducted.

5

FIGURE 6 Pre-trafficking In-situ Direct Shear Results.

6   **Simulated Aircraft Trafficking**

7   Each of the replicates and treatments were subjected 1,500 passes of simulated F-15E tire
8   traffic using AFRL's F-15 load cart. Some environmental cracking (postulated to be
9   shrinkage and/or thermal cracking) was observed prior to commencement of the trafficking
10   experiment. However, during the conduct of the trafficking experiment, these cracks
11   remained tight, and no FOD-creating distresses were observed.

12   **Post-Trafficking In-Situ Pull-Off Experiments**

13   The results of the post-trafficking in-situ pull-off experiments are summarized in the plot
14   shown in FIGURE 7. For all treatments the pull-off strength was non-zero, indicating that the
15   bond was not broken during the trafficking of the spall repairs. The highest post-trafficking
16   in-situ bond strength was observed for the cold planer, with the other methods having bond
17   strengths approximately one-half that of the cold planer. A pair wise t-test analysis indicated

1   that the observed difference in mean value between the cold planer all the other four methods
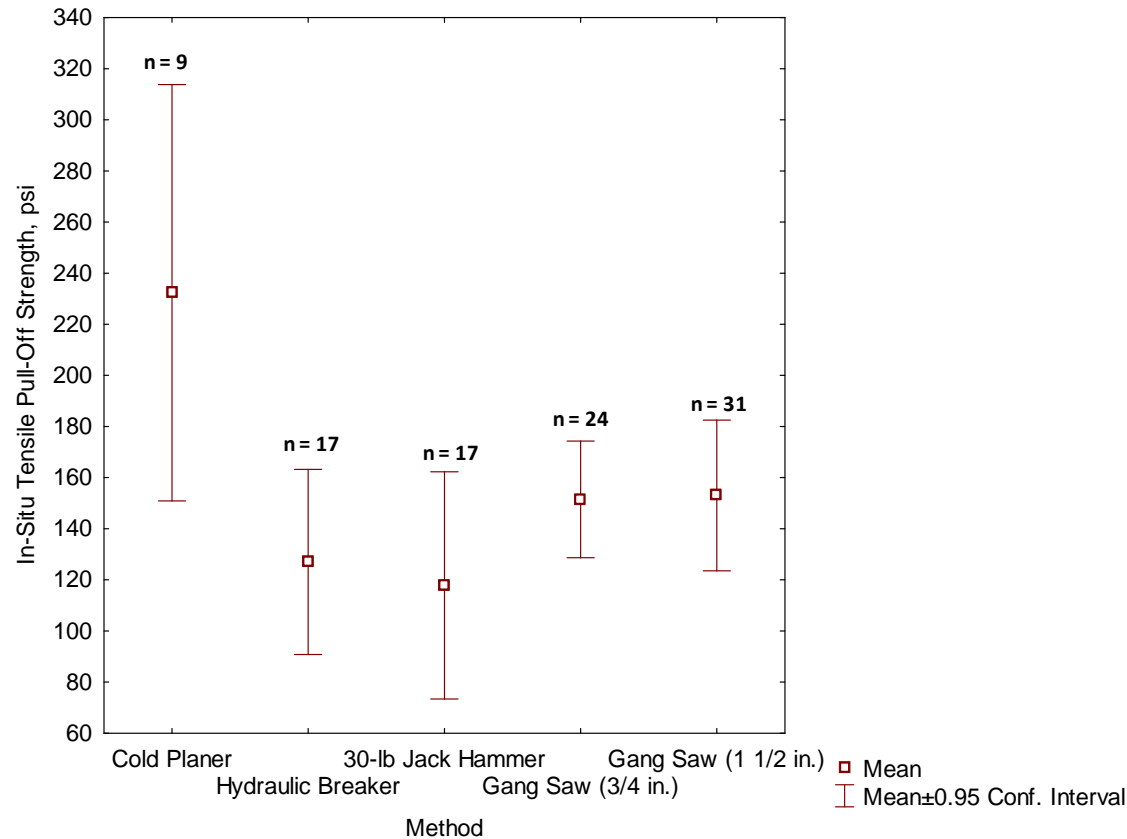2   were statistically significant at the 95 percent confidence level.
3

4
FIGURE 7   Post-trafficking In-situ Pull-off Results.

5   **Post-Trafficking Direct Shear Experiments**

6   The results of the post-trafficking direct shear experiments are summarized in the plot shown
7   in FIGURE 8. The greatest observed mean pull-off strength was for the gang saw at ¾ inch
8   spacing, followed, in order, by the gang saw at 1½ inches spacing, jackhammer, cold planer,
9   and finally the hydraulic breaker. However, only the hydraulic breaker was statistically
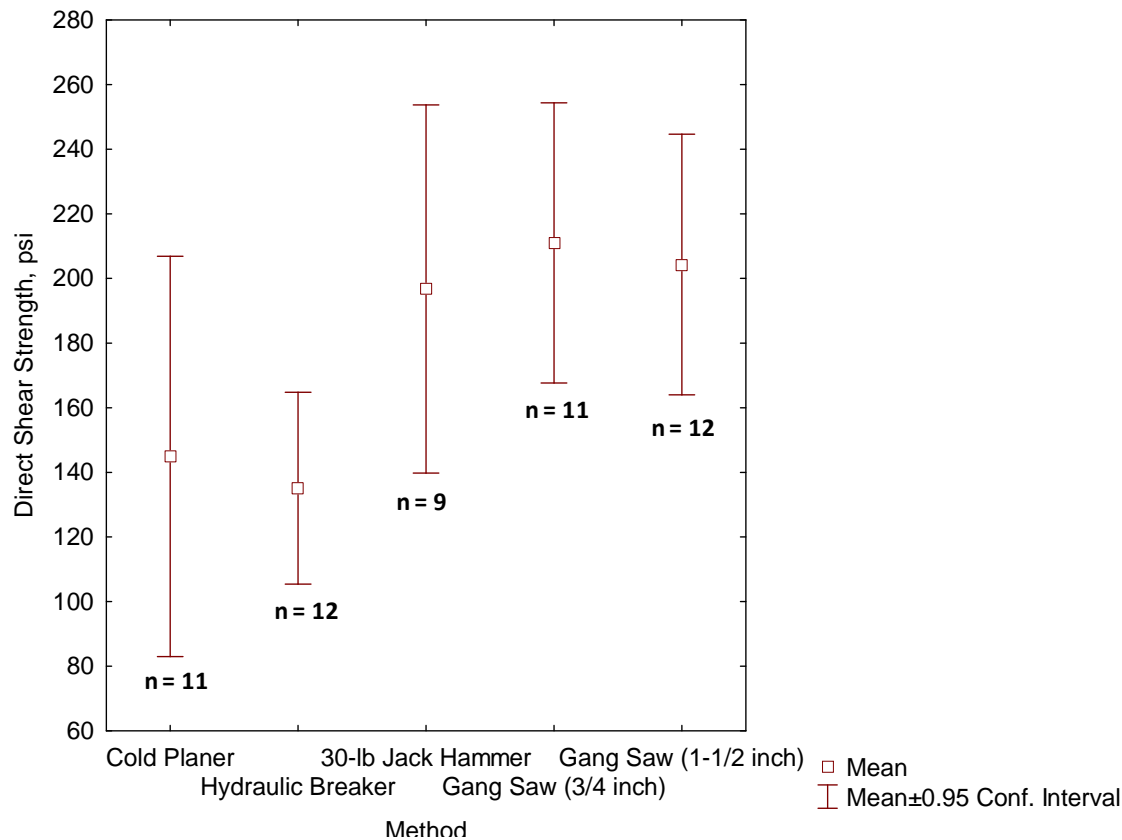10 significant.

FIGURE 8 Post-trafficking Direct Shear Results.

2   **Petrographic Examination Results**

3   The results of the URI scans were compared with scans from control cores (i.e., core
4   extracted from virgin areas adjacent to the spall repairs). The control cores contained a
5   number of small cracks in the paste which appeared to initiate at or be related to intrinsically
6   cracked aggregate. The only damage observed to significantly penetrate the surface was
7   observed in cores from the area excavated by the hydraulic breaker. In this case, large
8   aggregates near the surface were highly cracked. Thus, the results of the petrographic
9   examination revealed that only the hydraulic breaker produced significant subsurface damage
10 of the rock or paste at depths of up to ½ inch.
11

12 **Summary of Significant Results**

13 *Production Rate*

14 Each of the methods tested had a significant improvement in production rate over the 30-
15 pound jackhammer. The most efficient method was the cold planer, which, on average, was
16 approximately 58 percent more efficient than the jackhammer. It was the only method

1   investigated expected to consistently meet the research objective of excavating a nominal 2
2   foot square by 4-inch deep spall in 15 minutes or less. The second most efficient method was
3   the multiple blade (gang) saw. The 1½-inch blade spacing was significantly more efficient
4   than the ¾-inch blade spacing. The hydraulic breaker (excavator) was more efficient than the
5   control case (manual jackhammer), but it causes significant damage to the upper ½-inch or so
6   of the substrate materials.

7   *Bond Strength*

8   Pre-traffic bond strength data (in-situ direct tension tests and direct shear tests) indicated that
9   only the hydraulic breaker had significantly lower bond strength prior to trafficking with
10   1,500 passes of simulated F-15 load.
11   The post-trafficking bond strength data indicated that the cold planer method resulted
12   in significantly greater bond strength after 1,500 passes of simulated F-15 traffic. This is
13   evidence of significantly greater performance for this method of preparing a spall for
14   placement of rapid setting material.

15   *Petrographic Examination*

16   Petrographic examinations indicated that none of the methods investigated produced any
17   significant damage of the aggregate or paste below the surface with the exception of the
18   hydraulic breaker, which produced cracking the matrix and fractured aggregates up to ½ inch
19   below the top surface.

20   *Performance under Traffic*

21   Each of the replicates and treatments were subjected 1,500 passes of simulated F-15E traffic.
22   During the conduct of the testing, no cracking, spalling, or any other type FOD-creating
23   distresses were observed.
24   Some environmental cracking (postulated to be shrinkage and/or thermal cracking)
25   was observed prior to commencement of the trafficking experiment. However, during the
26   conduct of the trafficking experiment, these cracks remained tight, and no FOD-creating
27   distresses were observed.

28   **CONCLUSIONS AND RECOMMENDATIONS**

29   **Conclusions**

30   *Excavation Methods*

31   Five excavation methods (treatments) were used to prepare a nominal 2-foot-wide 2-foot-
32   long by 4-inch-deep spalls:
33   • Saw cut and 30-pound jackhammer (baseline or current standard),
34   • Saw cut and a hydraulic breaker on a skid steer tractor,
35   • Multiple-blade gang saw with saw spacing at ¾ inch,

1   • Multiple-blade gang saw with saw spacing at 1½ inches, and
2   • Cold planer attachment for a skid steer loader.
3   The control case was the 30-pound jackhammer. Each of the four methods tested had a
4   significant improvement in production rate over the 30-pound jackhammer. The most
5   efficient method was the cold planer, which, on average, was approximately 58 percent more
6   efficient than the jackhammer. The second most efficient method was the gang saw at 1½
7   inch spacing, followed by the hydraulic breaker, followed by gang saw with spacing at ¾
8   inch spacing. Only the cold planer can meet the requirement of being able to excavate 2-foot
9   square by 4-inch deep spall in no more than 15 minutes.

10   *Simulated Aircraft Trafficking*

11   Each of the replicates and treatments were subjected to 1,500 passes of simulated F-15E.
12   During the conduct of the testing, no load-related cracking, spalling, or any other type FOD-
13   creating distresses were observed.

14   *In-Situ Bond Strength*

15   In-situ bond tests were performed both prior to and after simulated aircraft trafficking. Pre-
16   trafficking, the greatest observed mean pull-off strength was for the cold planer, followed, in
17   order, by the jackhammer, gang saw at 1½ inches spacing, gang saw at ¾ inch spacing, and
18   finally the hydraulic breaker. However, only the differences in the means between the
19   hydraulic breaker and cold planer and hydraulic breaker and jackhammer were statistically
20   significant at the 95 percent confidence level, and one cannot statistically distinguish
21   between the means of the other treatments at the 95 percent confidence level.
22   The highest post-trafficking in-situ bond strength was observed for the cold planer,
23   with the other methods having bond strengths approximately one-half that of the cold planer.
24   The observed difference in mean value between the cold planer all the other four methods
25   were statistically significant at the 95 percent confidence level.

26   *Direct Shear Strength*

27   Analysis of the correlation between the in-situ tensile pull-off strength and the direct shear
28   strength experiments indicated that the two metrics of bond strength are positively correlated
29   with a correlation coefficient (R^2) of 0.66. However, the statistical significance of the direct
30   shear strength results was not as powerful as those of the in-situ direct pull off strengths.
31   Because the direct shear strength test is not an accepted test method per ASTM, it was
32   concluded that the results of the direct shear strength tests should not be used to draw
33   conclusions concerning the efficacy of the methods until further development and analysis of
34   this methodology is conducted.

35   *Petrographic Examination*

36   Petrographic examinations indicated that only the hydraulic breaker produced significant
37   subsurface damage of the rock or paste at depths of up to ½ inch.

1   **Recommendations**

2   The cold planer method should be adopted as a standard method of preparing spalls for
3   placement of a rapid-setting spall repair material. The cold planer equipment can be
4   purchased as an attachment to skid-steer loader. While the time to prepare a spall depends
5   upon the characteristics of the spall and the skill of the operator, use of this equipment
6   requires about half the time to prepare the spall as compared to the control case of a manual
7   jackhammer. The cold planer equipment, under the control of an experienced operator, can
8   prepare a two foot square by 4 inch deep spall for placement of rapid-setting material in less
9   than 15 minutes. Furthermore, spalls prepared with this method retain superior bond strength
10   after aircraft trafficking and are expected to provide superior performance compared to those
11   prepared with other conventional and experimental methods evaluated in the study.

12   **REFERENCES**

13   1. Speer, Benjamin S. *A Value-Focused Thinking Model for the Selection of the Best Rigid*
14   *Pavement Partial-Depth Spall Repair Material*, AFIT/GEM/ENS-07-4, Air Force
15   Institute of Technology, Wright-Patterson Air Force Base, OH, March 2007.
16   2. Department of the Air Force. *Spall Repair of Portland Cement Concrete (PCC) Airfield*
17   *Pavements in Expeditionary Environments*, ETL 07-8, Air Force Civil Engineer Support
18   Agency, Tyndall AFB, FL, 27 Jul 2007.
19   3. The American Concrete Institute. "Guide for the Selection of Materials for the Repair of
20   Concrete." ACI 546.3R-06, Farmington Hills, Michigan, December 2006.
21   4. Emmons, Peter. *Field Guide to Concrete Repair Application Procedures: Spall Repair of*
22   *Horizontal Concrete Surfaces*,   ACI RAP Bulletin 7, American Concrete Institute, 2005.
23   5. International Concrete Repair Institute. *Guide to Using In-Situ Tensile Pull-Off Tests to*
24   *Evaluate Bond of Concrete Surface Materials,* Guideline No. 03739, International
25   Concrete Repair Institute, Des Plaines, IL, March 2004.
26   6. ASTM. "Standard Test Method for Pull-Off Strength of Coatings Using Portable
27   Adhesion Testers," ASTM D4541-2, ASTM International, West Conshohocken, PA.,
28   2007.
29